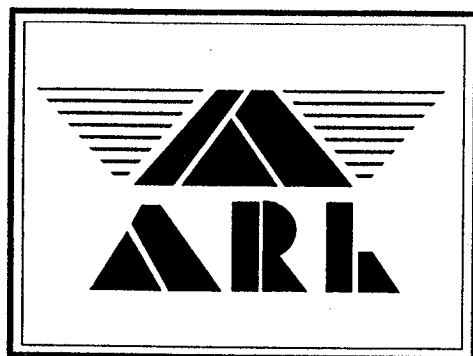


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**ATTENTION AND INFORMATION ACCESS  
EFFORT IN HEAD-UP DISPLAYS**

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## **Attentional Issues in Head-Up Displays**

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Head-up displays, or HUDs, have been around for quite some time, particularly in the military cockpit, where their assistance in combat operations has been invaluable (Weintraub and Ensing, 1992). Their introduction into civil aviation has been more recent, but still successful (Steenblik, 1992), while their appearance as a support for general aviation is more recent still. In spite of their enthusiastic acceptance by pilots, some concern remains regarding both optical issues (Iavecchia, Iavecchia, and Roscoe, 1988) and possible attentional issues. The latter relate both to the clutter caused by overlapping HUD imagery against the background and the possibility of cognitive capture, by which the compelling nature of the HUD images inhibit the detection of other critical events (Fischer, Haines, and Price, 1980; Weintraub and Ensing, 1992).

To examine these attentional questions, we have completed a series of six simulation studies at Illinois, examining the pilot's information processing and flight performance when using HUDs. These studies have focused in particular on the perception and attentional factors involved as pilots fly with HUDs in both low and high visibility conditions. Our research program is designed to address two issues. From a more basic perspective, we are trying to develop and validate a model of visual attention relevant to the processing of the overlapping images produced when the HUD is viewed against the background scene. The model is based on the contrast between space-based and object-based theories of visual attention (Kramer and Jacobson, 1991; Wickens and Long, in press). From a more applied perspective, our goal is to answer the designer's questions: how much information should go on a HUD, what should that information be, and how should it be formatted?

In carrying out the six studies, overviewed in Table 1, we have identified a number of important dichotomies, pertaining to **information, display, and pilot processing mechanisms**. These dichotomies are listed as follows:

### Information

**Near Domain** (on the display) versus **far domain** (in the world).

**Guidance** (necessary for lateral and vertical flight path control) versus **non-guidance** (system information, airspeed indicator, warnings, etc.).

## Displays

**Location:** Head-up (HUD) versus head-down (HDD).

**Conformality:** Conformal (overlying a far domain counterpart) versus non-conformal (neither overlying, nor moving in synchrony with a counterpart).

## Processing

**Focused Attention** (on either near or far domain information) versus **divided attention** (or integration), in which the task either requires, or has information available from both domains, and the pilot either must, or can sample both domains to do the task.

**Confusion & clutter versus scanning.** These are the two mechanisms that trade off, the former providing a cost for overlapping images in the HUD, the latter providing a cost for separated images in the HDD.

Typically our experiments have proceeded by manipulating two or more of the above dichotomous variables in factorial designs (e.g., the **displays** upon which different kinds of **information** is presented to perform different kinds of **information processing tasks**). In addition, some of our experiments have examined issues of information expectancy (Larish and Wickens, 1991), and image intensity and contrast (May and Wickens, 1995). As noted in Table 1, our studies have also been carried out at varying levels of simulation fidelity, addressing three different flight phases; cruise, landing, and taxi.

We have explicitly **not** examined optical issues of collimation (see Iavecchia et al., 1988; Weintraub and Ensing, 1992 for a discussion of these issues). With the exception of two studies (Larish and Wickens, 1991; Lasswell and Wickens, 1995), all of our simulations have presented all of the imagery (head-up, head-down, far domain) at the same optical distance from the pilot, and the imagery has been viewed directly, rather than through collimated lenses. This means that any comparisons in our experiments between head-up and head-down location have not been confounded by differences in visual accommodation.

A typical experiment will require the pilot to fly a number of trials (e.g., landings, or flight segments), during both IMC (only instruments visible) and VMC (instruments and background both visible). Pilots are assessed on the lateral and vertical accuracy of their flight path, their airspeed control and, often on the

speed and accuracy with which they detect events either depicted on the display (HUD or HDD) or in the far domain. Sometimes these events are **expected**, in that they occur repeatedly throughout the experiment, and sometimes they are **unexpected**, in that they will occur only once (e.g., an aircraft suddenly taxis onto or across the runway toward which the pilot is approaching). Our HUD designs have been adopted from designs used by Flight Dynamics, Inc., Flight Vision Systems and, more recently, proposed NASA prototypes for taxi HUDs (Lasswell and Wickens, 1995).

A very cursory and selected overview of the results is provided on the right side of Table 1, in which a "+" beside a particular entry, means that the entry in question yielded a significant benefit for head-up presentation. a "-" means that there is a HUD cost, and a "0" means that no statistically significant effect was observed. Overall, our collective interpretation of the results indicates an ongoing "tug of war" between the HUD advantages of reduced visual scanning, and the HUD costs of confusion and clutter. From experiment to experiment, one or the other influence may be more dominant. However, we can systematically identify these influences. In particular, the HUD advantages of reduced scanning prevail (a) to the extent that the imagery is conformal (Wickens and Long, 1995), and (b) to the extent that events to be detected are expected. In contrast, the costs of clutter are enhanced by non-conformal imagery, and are particularly evident in the detection of unexpected events. It is this difficulty in detecting unexpected events either viewed through the HUD (like a runway incursion), or on the HUD imagery itself, that manifests the phenomenon of attentional or cognitive capture (Weintraub and Ensing, 1992). We also have some weaker evidence that a benefit of conformal imagery is that it "fuses" the near and far domain, and hence allows the division of attention between those domains to proceed more effectively.

In conclusion, we have provided objective documentation of the advantages of HUDs for many routine flight control tasks, in comparison with head-down presentation of the same imagery at the same optical distance. Yet we offer some caution pertaining to the problems of clutter in both routine and in particular, unexpected information processing. The HUD is clearly a valuable asset to the pilot but still must be implemented with caution and constraint, and careful attention must be given to the pilot's task and information needs.

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+ = HUD ADVANTAGE

-- = HUD COST

	DOMAIN	FIDELITY	MANIPULATION	FLIGHT CONTROL		EVENT MONITORING	
				CONF	NC	EXPECTED	UNEXPECTED
LARISH & WICKENS (1991)	LANDING	MEDIUM	LOCATION		0	NEAR + FAR +	NEAR -- FAR --
WICKENS, MARTIN-EMERSON, & LARISH (1993)	LANDING	HIGH	LOCATION		+	NEAR + <sup>1</sup> FAR +	FAR 0
MARTIN-EMERSON & WICKENS (1992)	LANDING	HIGH	LOCATION OF CLUTTER  CONFORMALITY OF SYMBOLOGY			NEAR +  FAR 0	
WICKENS & LONG (1995 in press)	LANDING	HIGH	LOCATION OF GUIDANCE  CONFORMALITY OF GUIDANCE	+	0	NEAR 0 <sup>1</sup>	FAR --
MAY & WICKENS (1995)	CRUISE	LOW	LOCATION OF GUIDANCE; INTENSITY (CONTRAST)		--  --	NEAR --  FAR +	
LASSWELL & WICKENS (1995)	TAXI	HIGH	LOCATION OF GUIDANCE  CONFORMALITY OF GUIDANCE	+	+	NEAR 0	FAR 0

<sup>1</sup> AIRSPEED TRACKING